



Good Afternoon Chairpersons Gerratana, Somers, Steinberg, Ranking Member Betts and distinguished members of the Public Health Committee. My name is Jason Klein, I'm President of Force3 Pro Gear located in Derby, Connecticut. Force3 Pro Gear is a visionary, 21st century company dedicated to enhancing and revolutionizing protective equipment for active participants in all sports. Our mission is to develop and distribute only the highest quality, most protective possible products for professional and amateur athletes and officials.

Thank you for the opportunity to testify in support of House Bill 5291 An Act Concerning Access to Information Regarding the Safety of Sports Helmets. By way of background, I spent 10 years as a minor league umpire and experienced first hand the importance of wearing the proper protective gear. It took many years designing, prototyping and performing exhaustive testing, to finally create a catcher's and umpire's mask that contains a patented shock suspension system that sets us apart from other masks currently on the market. As a Connecticut company creating this breakthrough technology, we have a great story to tell, but unfortunately the non-profit organization that currently sets the safety standards for equipment used in little leagues and high school athletics, prohibits our company from sharing with the public our outstanding safety data.

The National Operating Committee on Standards for Athletic Equipment (also known as "NOCSAE") was formed in 1969 to commission research directed toward injury reduction. Little league and high school athletics through their respective rules require protective equipment used in baseball and softball to meet standards set by NOCSAE. The NOCSAE helmet standard uses a pass/fail threshold to determine whether or not a helmet meets the standard performance criteria. The NOCSAE pass/fail threshold is 1200 Severity Index units, or SI. A helmet must test below 1200 SI in all 16 designated and random impact locations, including impacts at a helmet in ambient, high and low temperatures.

Our Force3 hockey-style mask has undergone the required testing from a NOCSAE approved independent testing facility, meets the standard and in fact, scored significantly lower than the 1200 severity index threshold. The problem we encountered is that pursuant to our licensing agreement with NOCSAE, we are prohibited from sharing our severity index results with the public. In fact, there's been no place for an athlete or parent seeking helmet safety information to turn and no way for them to compare results with other helmets currently on the market.

In 1993, the National Highway and Transportation Safety Administration (NHTSA) introduced the nation's 5 Star Rating system to help consumers make informed safety choices when buying new vehicles. Public disclosure of these rankings caused automakers to engineer vehicles with the goal of getting a five-star rating. More recently, in 2009 Connecticut instituted a similar rating system within the restaurant industry with the intent to not only educate consumers about an establishment's degree of compliance with the Connecticut Public Health Code, but also to incentivize those establishments that scored lower to do better. No such incentive currently exists for helmet manufacturers because all helmets that fall within the 0 to 1200 SI range are considered to "pass" and therefore create the public perception that they all provide the same level of protection.



The certifying body, NOCSAE, has contended that there is no sliding scale that shows that helmets with a lower SI are "measurably better"; however, there are studies that say otherwise (*please refer to my written testimony for more information concerning the findings of the Virginia Tech Study). Although some would argue that the standard as whole should be revised to demand better protection, I understand that that is a much bigger discussion - one that I'm happy to have. However, passage of House Bill 5291 will provide the first step to not only educate consumers, but also to incentivize an industry to continually strive to do better. Giving the consumer more information about how all helmets perform and granting them the opportunity to find this information more readily is significantly important to preventing serious head injuries. I thank you for your time and consideration of this important issue and am happy to answer any questions you may have.

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$$\downarrow SI = \downarrow R(a)$$

LOWER SEVERITY INDEX = LOWER CONCUSSION RISK*

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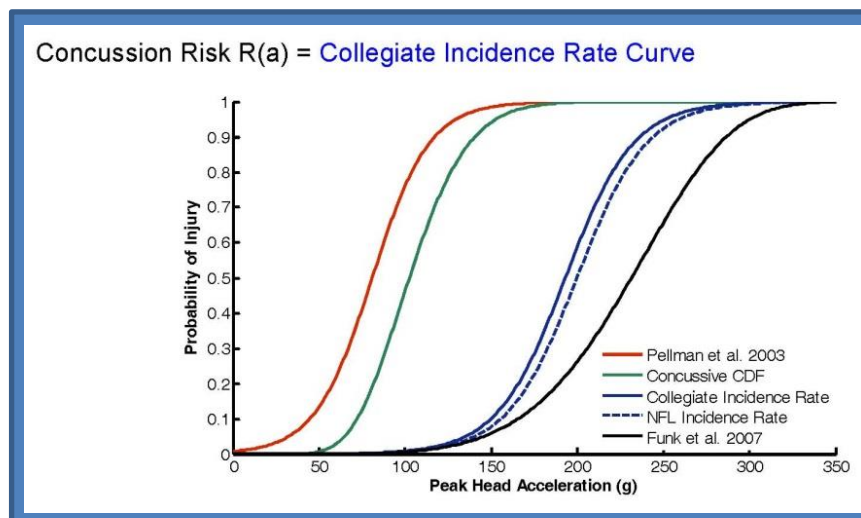


$$\downarrow SI = \downarrow R(a)$$

LOWER SEVERITY INDEX = LOWER CONCUSSION RISK*

* In May 2013, the Biomedical Engineering Society published a peer reviewed research report from Virginia Tech that was sponsored by the National Institute of Health and is posted on the NIH website. This report concluded: a helmet that lowers (head) acceleration predicts a lower incidence of concussion. Head acceleration (A) is the major component of the NOCSAE Severity Index (“SI”), $SI = \int_0^T A^{2.5} dt$, so lowering acceleration lowers Severity Index, which in turn lowers the risk of concussion. Further, helmets that better manage impact energies result in lower head accelerations and thus a lower Severity Index. In conclusion,

Lower Severity Index = Lower Concussion Risk; stated formulaically, $\downarrow SI = \downarrow R(a)$



COACHES IN COURT: Coaches, Athletic Trainers, And Equipment Managers Are Next On Lawyers' Hit List

An institution must, at all times, meet or exceed all applicable standards of care. Institutions should provide athletes access to head and body safety equipment that reduces the Severity Index as much as 50%. A member of an athletic department that denies athletes access to such safety equipment can create a potential liability for themselves, the athletic department, as well as the institution.

It is not rare for a coach to be sued for negligence after a student-athlete suffers an injury or dies. But now coaches are facing criminal charges relating to the death of their athletes.

"Blame rolls uphill," says an attorney. It starts with the coach and athletic trainer who were working with the athletes on a daily basis. They're the ones who have to make sure the situation is being managed on the front lines. But the administrator also has a duty to make sure the coach and athletic trainer are aware of and are following the rules."

The NFL and NCAA lawsuits have raised the bar on the duty of care owed to athletes. Referred to as "Coaches Duty of Care", it's ensuring all reasonable steps are taken to overcome foreseeable risks, safeguarding injured athletes, providing the best in head and body protection."

How much does an athletic department have to do in order to satisfy the legal standard of care? The courts have stated that a coach must take all reasonable steps to prevent injury to athletes including ensuring participants are prepared and properly equipped for all aspects of the activity.

In order to accurately understand the current standard, one must first understand what duty of care is and when that duty has been breached. To claim negligence against a coach, athletic trainer, equipment manager, or teacher, a claimant must establish the following:

- A. Does the coach owe the athlete a duty of care? When you are in a position of trust, care or power, a duty of care will almost always be placed upon you. Therefore, a coach will have a duty of care to offer to their athletes the best protection.
- B. Has the coach breached the duty of care? A coach must provide reasonable care to their athletes, matching what would be expected from a reasonable, confident and careful coach acting in similar circumstances.
- C. Was the injury sustained due to the negligence of the coach? When a judge looks at such cases he must find a reasonable degree of proximity between the coach's breach of the reasonable standard and the damage suffered.

WARNING: Any player in any sport can sustain a head injury with even the very best head protection. No helmet pad can prevent or eliminate the risk of concussions or other serious head injuries while playing sports. Scientists have also not reached agreement on how the results of impact absorption tests relate to concussions. No conclusions about a reduction of risk or severity of concussive injury should be drawn from impact absorption tests. Further, the claims and opinions expressed herein are those of the individual(s) and not necessarily the claims or opinions of Unequal Technologies Company, its staff or affiliates.

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Brain Injury Prediction: Assessing the Combined Probability of Concussion Using Linear and Rotational Head Acceleration

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Abstract

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Recent research has suggested possible long term effects due to repetitive concussions, highlighting the importance of developing methods to accurately quantify concussion risk. This study introduces a new injury metric, the combined probability of concussion, which computes the overall risk of concussion based on the peak linear and rotational accelerations experienced by the head during impact. The combined probability of concussion is unique in that it determines the likelihood of sustaining a concussion for a given impact, regardless of whether the injury would be reported or not. The risk curve was derived from data collected from instrumented football players (63,011 impacts including 37 concussions), which was adjusted to account for the underreporting of concussion. The predictive capability of this new metric is compared to that of single biomechanical parameters. The capabilities of these parameters to accurately predict concussion incidence were evaluated using two separate datasets: the Head Impact Telemetry System (HITS) data and National Football League (NFL) data collected from impact reconstructions using dummies (58 impacts including 25 concussions). Receiver operating characteristic curves were generated, and all parameters were significantly better at predicting injury than random guessing. The combined probability of concussion had the greatest area under the curve for all datasets. In the HITS dataset, the combined probability of concussion and linear acceleration were significantly better predictors of concussion than rotational acceleration alone, but not different from each other. In the NFL dataset, there were no significant differences between parameters. The combined probability of concussion is a valuable method to assess concussion risk in a laboratory setting for evaluating product safety.

Keywords: Mild traumatic brain injury, Biomechanics, Football, Helmet, Angular, Risk curve

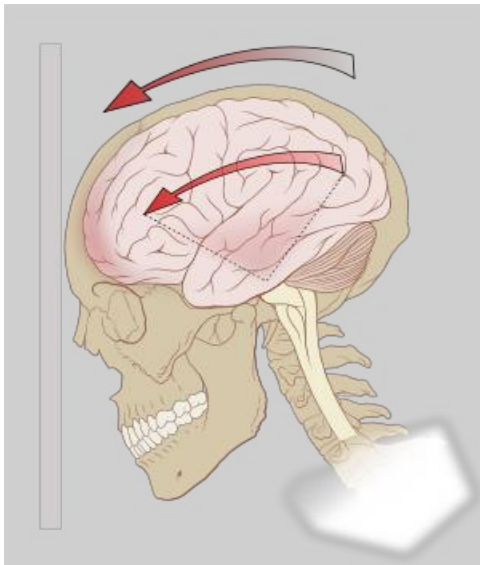
Introduction

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With as many as 3.8 million sports-related concussions occurring annually in the United States and research suggesting possible long term neurodegenerative processes resulting from repetitive concussions, reducing the incidence of concussion in sports has become a public health priority. [32,42,43](#) While limiting the number of head impacts in sports through rule changes and improved education for coaches and players have an important role in reducing concussion incidence, incidental head impacts cannot be removed from sports. [10](#) It has been suggested that the monitoring of head impacts to identify high risk events and alert medical personnel to perform a concussion evaluation may reduce the incidence and severity of concussions by preventing subsequent impacts that may cause brain injury due to impact. [21](#) Part of the remaining burden of reducing concussion incidence relies on the improvement of head protection. Helmets currently used in sports are designed to pass test standards that evaluate a helmet's ability to prevent skull fracture. [40,41](#) As a result, skull fractures have essentially been eliminated in helmeted sports, but these helmets are not designed to guard against concussion. [51](#) One of the challenges in designing helmets to account for concussive forces is accurately modeling concussion risk in the laboratory. This article focuses on the kinematic parameters used to predict brain injury.



Is Concussion Litigation The Next Big Threat To The NCAA?



A diagram of the forces on the brain in concussion (Photo credit: Wikipedia)

By now, most sports fans are familiar with the class-action concussion lawsuit against the National Football League, which accuses the NFL, among things, of having negligently failed to warn players about the risks of concussions and concealed informational studies about the long-term effects of concussions.

There is also a similar lawsuit making its way through the court system against the NCAA – *Arrington v. National Collegiate Athletic Association*. However, many of the potentially mitigating factors that could reduce the NFL’s legal exposure do not seem to avail themselves to the NCAA.

First, there is the issue of “**duty of care**” — the standard of legal obligation placed on a given entity to prevent negligent acts. Although the NFL may owe a duty of care to protect its athletes from head injuries, one would surmise this duty to be far greater in the context of the NCAA, which, according to its own website, was founded in 1905 “**to protect young people from the dangerous and exploitive (sic) athletic practices of the time.**” These practices specifically included risks of head and neck injuries.

Brain Injury Prediction: Assessing the Combined Probability of Concussion Using Linear and Rotational Head Acceleration

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Associate Editor Peter E. McHugh oversaw the review of this article.

Abstract—Recent research has suggested possible long term effects due to repetitive concussions, highlighting the importance of developing methods to accurately quantify concussion risk. This study introduces a new injury metric, the combined probability of concussion, which computes the overall risk of concussion based on the peak linear and rotational accelerations experienced by the head during impact. The combined probability of concussion is unique in that it determines the likelihood of sustaining a concussion for a given impact, regardless of whether the injury would be reported or not. The risk curve was derived from data collected from instrumented football players (63,011 impacts including 37 concussions), which was adjusted to account for the underreporting of concussion. The predictive capability of this new metric is compared to that of single biomechanical parameters. The capabilities of these parameters to accurately predict concussion incidence were evaluated using two separate datasets: the Head Impact Telemetry System (HITS) data and National Football League (NFL) data collected from impact reconstructions using dummies (58 impacts including 25 concussions). Receiver operating characteristic curves were generated, and all parameters were significantly better at predicting injury than random guessing. The combined probability of concussion had the greatest area under the curve for all datasets. In the HITS dataset, the combined probability of concussion and linear acceleration were significantly better predictors of concussion than rotational acceleration alone, but not different from each other. In the NFL dataset, there were no significant differences between parameters. The combined probability of concussion is a valuable method to assess concussion risk in a laboratory setting for evaluating product safety.

Keywords—Mild traumatic brain injury, Biomechanics, Football, Helmet, Angular, Risk curve.

INTRODUCTION

With as many as 3.8 million sports-related concussions occurring annually in the United States and research suggesting possible long term neurodegenerative processes resulting from repetitive concussions, reducing the incidence of concussion in sports has become a public health priority.^{32,42,43} While limiting the number of head impacts in sports through rule changes and improved education for coaches and players have an important role in reducing concussion incidence, incidental head impacts cannot be removed from sports.¹⁰ It has been suggested that the monitoring of head impacts to identify high risk events and alert medical personnel to perform a concussion evaluation may reduce the incidence and severity of concussions by preventing subsequent impacts that may cause brain injury due to impact.²¹ Part of the remaining burden of reducing concussion incidence relies on the improvement of head protection. Helmets currently used in sports are designed to pass test standards that evaluate a helmet's ability to prevent skull fracture.^{40,41} As a result, skull fractures have essentially been eliminated in helmeted sports, but these helmets are not designed to guard against concussion.⁵¹ One of the challenges in designing helmets to account for concussive forces is accurately modeling concussion risk in the laboratory. This article focuses on the kinematic parameters used to predict brain injury.

Kinematic parameters of the head are commonly used to assess brain injury risk because they are thought to be indicative of the inertial response of the brain.⁵³ Traditionally, research investigating the biomechanics associated with brain injury has focused on two injury modes: injury resulting from linear acceleration and injury resulting from rotational acceleration. Linear acceleration-based brain injury is thought to result from a transient intracranial pressure gradient, while rotational acceleration-based brain injury is thought to result from a

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compares the empirical cumulative distribution functions (CDF) for each dataset.

Due to large number of impacts in the HITS dataset that did not result in concussion, subsets of the HITS dataset were also analyzed. Using peak resultant linear acceleration to gauge impact severity, the top 50% and top 25% of HITS impacts were investigated. The top 50% of sub-concussive impacts in the HITS dataset consisted of impacts with peak linear accelerations greater than 19 g and had average accelerations of 38 ± 20 g and 1528 ± 984 rad/s². The top 25% of sub-concussive impacts in the HITS dataset consisted of impacts with peak linear accelerations greater than 31 g and had average accelerations of 52 ± 21 g and 2036 ± 1124 rad/s².

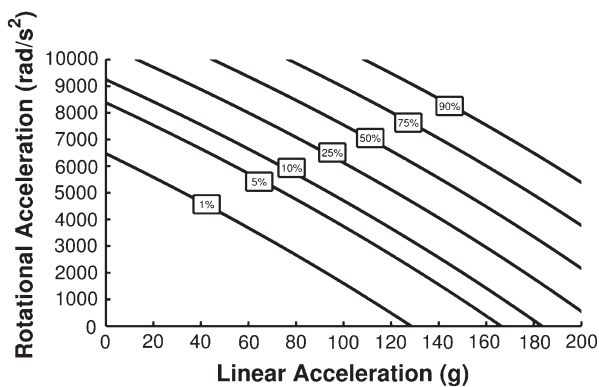


FIGURE 2. Combined probability of concussion contours relating overall concussion risk to linear and rotational head acceleration.

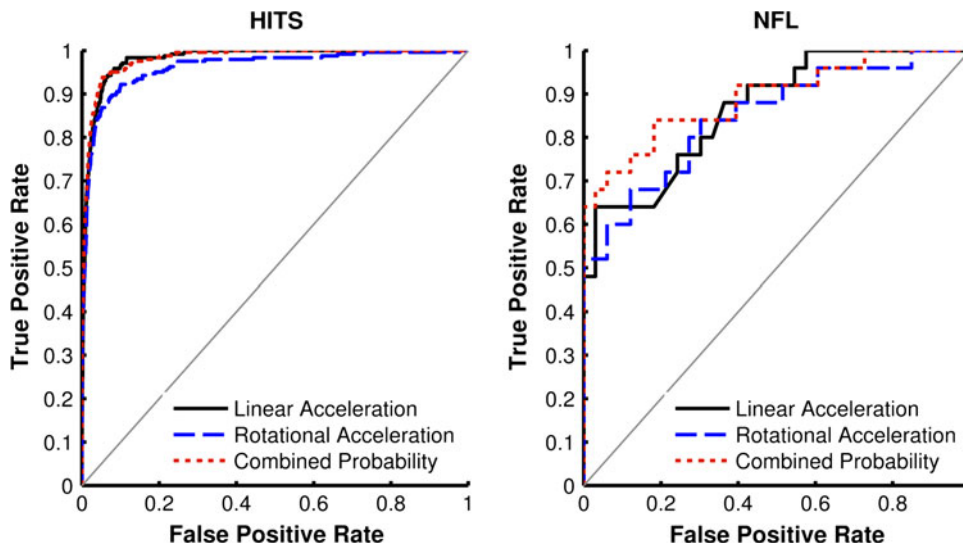


FIGURE 3. ROC curves for the HITS (left) and NFL (right) datasets for linear acceleration, rotational acceleration, and the combined probability of concussion.

The combined probability of concussion for each impact in each dataset was determined using Equation 2. For each dataset, the capabilities of linear acceleration, rotational acceleration, and the combined probability of concussion to accurately predict concussion incidence were quantified using receiver operating characteristic (ROC) curves. For each parameter, the area under its ROC curve (AUC) was compared to the predictive capability of random guessing ($AUC = 0.5$) using a significance level of $p < 0.05$. Furthermore, the predictive capability of each parameter was compared with Hanley's method of direct comparison of AUCs using a significance level of $p < 0.05$ for each dataset.²⁶

RESULTS

The regression coefficients for the combined probability of concussion equation were determined (Eq. (2)), with $\beta_0 = -10.2$, $\beta_1 = 0.0433$, $\beta_2 = 0.000873$, and $\beta_3 = -0.000000920$. Risk contours relating peak linear and rotational head acceleration to concussion risk are shown in Fig. 2.

$$CP = \frac{1}{1 + e^{-(10.2 + 0.0433 \cdot a + 0.000873 \cdot x - 0.000000920 \cdot ax)}} \quad (2)$$

For the HITS and NFL datasets, ROC curves were generated for linear acceleration, rotational acceleration, and the combined probability of concussion (Fig. 3). Table 1 displays the AUC with 95th percentile confidence intervals for each parameter for both datasets. All parameters were better predictors of concussion than

TABLE 2. For the top 50% and top 25% of HITS data, the area under each ROC curve (AUC) for linear acceleration, rotational acceleration, and the combined probability of concussion was significantly different (denoted by p) than the AUC associated with random guessing (AUC = 0.5).

	Top 50% of HITS		Top 25% of HITS	
	AUC [95% CI]	p	AUC [95% CI]	p
Linear acceleration	0.962 [0.945–0.979]	<0.0001*	0.932 [0.909–0.954]	<0.0001*
Rotational acceleration	0.934 [0.913–0.956]	<0.0001*	0.898 [0.871–0.924]	<0.0001*
Combined probability	0.964 [0.947–0.980]	<0.0001*	0.937 [0.916–0.958]	<0.0001*

95th percentile confidence intervals (95% CI) for each AUC are provided in brackets.

*A significance threshold of $p < 0.05$ was used.

TABLE 3. Comparison of false positive rates for each parameter at 75 and 90% true positive rates in each dataset.

	75% True positive rate			90% True positive rate		
	Linear accel. (%)	Rotational accel. (%)	Combined probability (%)	Linear accel. (%)	Rotational accel. (%)	Combined probability (%)
HITS	2.0	2.3	1.6	4.9	8.8	4.0
NFL	24.4	27.3	12.1	42.4	51.5	39.4
50th % HITS	4.0	4.5	3.1	9.9	17.6	8.0
25th % HITS	7.8	9.1	6.2	19.7	29.6	15.9

combined probability of concussion produced lowest false positive rates in all HITS datasets (Table 3).

DISCUSSION

This study introduces a new injury metric, the combined probability of concussion, which computes the overall risk of concussion based on the peak linear and rotational accelerations experienced by the head during impact. The combined probability of concussion is unique in that it determines the likelihood of sustaining a concussion for a given impact, regardless of whether the athlete would report the injury or not. This was accomplished by adjusting the HITS dataset to account for an estimated underreporting rate during development of the risk curve. To side with conservatism, a greater underreporting rate was used in this analysis than previous independent linear and rotational acceleration risk curves that considered underreporting.^{51,53} Linear and rotational acceleration are considered because they both likely contribute to concussion risk and are thought to be associated with different injury mechanisms.^{30,44,57} Linear acceleration of the head is associated with a transient intracranial pressure gradient, while rotational acceleration of the head is associated with a strain response. Experiments designed to induce brain injury in animals have produced injury through isolated linear acceleration and isolated rotational acceleration events. Furthermore, Hardy *et al.*²⁸ measured the pressure and strain response of the human cadaver head to impact. Impacts similar in severity to those experienced in football were

modeled, and kinematic parameters were related to the pressure and strain response of the brain. Peak pressure increased with increasing linear acceleration of the head. Peak strains were less than 9% and brain motion correlated with rotational speed. For these reasons, both linear and rotational acceleration are considered in the combined probability of concussion.

Data from two different methodologies used to investigate the biomechanics of concussions were analyzed in this study. The HITS dataset was comprised of data collected from instrumented football players, while the NFL dataset was generated through laboratory reconstructions using crash test dummies. Even though data were generated from two different methodologies, the peak linear and rotational accelerations associated with concussion are similar. The primary difference between the two datasets is the sub-concussive subset. The HIT System allowed for the recording of every head impact a player experienced during games and practices while he was instrumented. As a result, the HITS dataset includes a vast number of impacts that did not result in concussion, and is more representative of the total head impact exposure that football players experience.^{17,53} The NFL dataset was generated from laboratory reconstructions that made it impractical to consider the thousands of head impacts experienced by NFL players, and instead only modeled some of the more severe impacts that could be characterized from video analysis.⁴⁸ Both datasets are valuable tools for evaluating injury predictors, but it is important to understand these differences between the HITS and NFL data.

**STANDARD TEST METHOD AND
EQUIPMENT USED IN EVALUATING THE
PERFORMANCE CHARACTERISTICS OF
PROTECTIVE HEADGEAR/EQUIPMENT**

NOCSAE DOC (ND) 001- 11m11

Prepared By



**NATIONAL OPERATING COMMITTEE
ON STANDARDS FOR ATHLETIC EQUIPMENT**

Revised: January 2011
Effective no later than January 2012

3.32 Retention System: The complete assembly that secures the helmet in a stable position on the wearer's head.

3.32.1 Chin Strap: A component of the helmet retention system which, when properly adjusted, rests on or encompasses the anterior and inferior most portions of the user's face.

3.32.2 Neck Strap: A component of the helmet retention system which, when properly adjusted, rests beneath the user's mandible.

3.32.3 Primary Retention: If the helmet is equipped with both a chinstrap and a neck strap, the neck strap is the component to be tested.

3.33 **Severity Index: A measure of the severity of impact with respect to the instantaneous acceleration experienced by the headform as it is impacted. Acceptable Severity Index (SI) levels measured during impact cannot exceed the limit specified in the individual standard performance specification.**

The Severity Index is defined as:

$$SI = \int_0^T A^{2.5} dt$$

Where: A is the instantaneous resultant acceleration expressed as a multiple of g (acceleration of gravity); dt are the time increments in seconds; and the integration is carried out over the essential duration (T) of the acceleration pulse.

For purposes of electronic data gathering, the integration as called for in this formula must begin after the system triggers but before the initial signal rises above 4 g's. The integration must then end when the signal falls below 4 g's, after it has peaked.

3.34 Shell: The exterior casing of a helmet. Normally the rigid structural component of a helmet.

3.35 Shimming: Refers only to the situation where a critical size is too large for the largest headform. A helmet too large can be shimmed to approximate fit so long as the shim material is of a mechanical property of low density and compression when compared to the primary energy management system used in the helmet. Shims must be placed in such a way that no part of the shim material is involved in the direct, initial impact. The helmet shall be shimmed so that the impacted area is fit to the head as intended for that area if the helmet were a proper fit to the headform. Additional time of up to three extra minutes shall be allowed for the onset of testing for conditioned samples to facilitate shim placement.

3.36 Signal Conditioner: A module of the Severity Index computation system that conditions the input for the Vector Analyzer and Severity Index computation system. It will excite and condition the signals from a triaxial accelerometer of a specific type, or accept ± 5 volts of maximum input directly.

Note - PC based, or other digital signal processing systems, if used, may replace the dycal and/or signal conditioner. In those instances, system compatibility and capabilities must be demonstrable.

Development of the STAR Evaluation System for Football Helmets: Integrating Player Head Impact Exposure and Risk of Concussion

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(Received 28 February 2011; accepted 2 May 2011; published online 7 May 2011)

Associate Editor Thurmon E. Lockhart oversaw the review of this article.

Abstract—In contrast to the publicly available data on the safety of automobiles, consumers have no analytical mechanism to evaluate the protective performance of football helmets. The objective of this article is to fill this void by introducing a new equation that can be used to evaluate helmet performance by integrating player head impact exposure and risk of concussion. The Summation of Tests for the Analysis of Risk (STAR) equation relates on-field impact exposure to a series of 24 drop tests performed at four impact locations and six impact energy levels. Using 62,974 head acceleration data points collected from football players, the number of impacts experienced for one full season was translated to 24 drop test configurations. A new injury risk function was developed from 32 measured concussions and associated exposure data to assess risk of concussion for each impact. Finally, the data from all 24 drop tests is combined into one number using the STAR formula that incorporates the predicted exposure and injury risk for one player for one full season of practices and games. The new STAR evaluation equation will provide consumers with a meaningful metric to assess the relative performance of football helmets.

Keywords—Concussion, Mild traumatic brain injury, Acceleration, Risk, Exposure, HITS, Impact.

INTRODUCTION

Recent research has suggested that there are as many as 3.8 million sports-related concussions each year in the United States, with participation in football resulting in the highest incidence of injury.^{8,29} Studies showing the potential long-term effects of these injuries have put sports-related concussions under the national spotlight as a primary health concern.^{16,35,36} Furthermore, there is concern that repetitive sub-concussive head impacts in

sports may lead to neurocognitive deficits.^{18,19,25} While limiting the number of head impacts in sports is an important component of reducing injury incidence, improving head protection is another essential element of injury mitigation.⁷ This article focuses on a new mechanism to evaluate the protective capabilities of football helmets.

Substantial effort has been invested in researching head acceleration in relation to brain injury.²⁷ Head acceleration is thought to be indicative of the inertial response of the brain, and therefore is used to predict brain injury.²⁷ All head injury safety standards for automobiles and helmets (motorcycle, sports, or bicycle) use measured humanoid head acceleration (or a function of head acceleration) during specified testing conditions to determine whether a product is safe to sell to consumers. While the Federal Motor Vehicle Safety Standards (FMVSS) 201 and 208 govern whether an automobile is safe to sell using pass/fail injury criteria, the New Car Assessment Program (NCAP) provides consumers with a quantitative metric of the relative safety between automobile models.^{23,28} NCAP is a valuable tool for consumers who are concerned with safety.

In contrast to the publicly available NCAP safety data on automobiles, consumers have no information on the relative impact performance between different helmets; moreover, there is no quantified metric that provides meaningful interpretation of the test results. The National Operating Committee on Standards for Athletic Equipment (NOCSAE) provides a set of voluntary standards that are designed to assess a helmet's ability to prevent skull fracture. NOCSAE certification involves testing helmets through a series of drop tests, in which every drop test must result in a head form impact response below a specified threshold. The NOCSAE standards have done an excellent job of

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The STAR Rating System for Football Helmets

STAR = Summation of Tests for the Analysis of Risk

The STAR value for each helmet model is derived from 120 impacts on 3 new helmets using the following equation and methodology:

$$STAR = \sum_{L=1}^4 \left(\sum_{H=1}^6 E(L, H) \bullet R(a) \right)$$

Using NOCSAE style tests with the following nomenclature:

L = helmet location, four total: front, top, side (combined), and rear

H = drop height, six total: 60", 48", 36", 24", 12", and lowest

E = exposure (function of drop height), number of impacts at that drop height for that location a player may experience in one year

R = Concussion injury risk (function of peak acceleration)

a = peak resultant acceleration

$$STAR = \sum_{Location=1}^4 \left(\sum_{Height=1}^6 Exposure(L, H) \bullet Risk(a) \right)$$

The STAR value represents a **Generalized Concussion Incidence**

In other words, the STAR value is the number of concussions that one player may experience through the duration of playing one complete season with a specific helmet.

So, the lower the STAR value, the better the helmet at reducing the risk of concussion, and subsequently the higher '# stars' in the rating system.

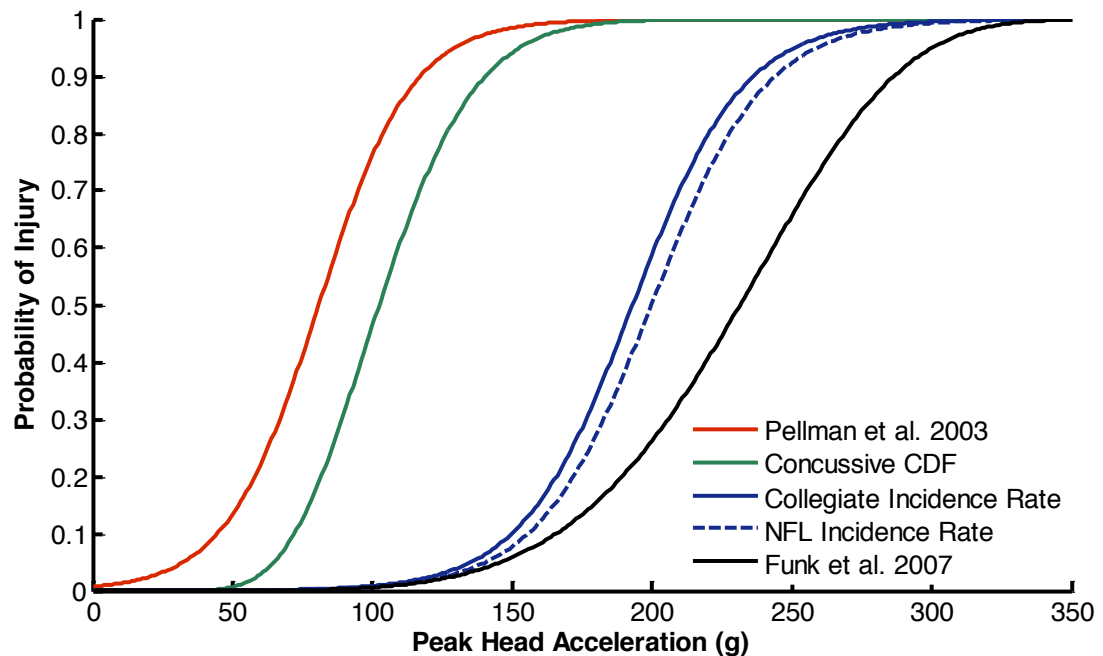
Limitations

- 1) Any player in any sport can sustain a head injury with even the very best head protection.
- 2) This analysis is based on data trends and probabilities, and therefore a specific person's risk may vary. This variation is likely dominated by genetic differences, health history, and impact factors such as muscle activation.
- 3) The exposure is for a starting competitive collegiate football player for a full season of practices and games; however, it can be scaled for any given exposure in high school or NFL.
- 4) All head impacts result in both linear and rotational accelerations. **This methodology utilizes only linear acceleration as currently there is substantial data on linear accelerations relating to concussion risk. Moreover, linear and rotational accelerations are highly correlated, and in general lowering linear will lower rotational.** As more data become available for rotational accelerations associated with concussions, this methodology could be modified to include them.

Risk

$$STAR = \sum_{L=1}^4 \left(\sum_{H=1}^6 E(h) \cdot R(a) \right)$$

Concussion Risk $R(a)$ = Collegiate Incidence Rate Curve



$$Risk = \frac{1}{1 + e^{-(\alpha x + \beta)}}$$

Where

x = peak resultant linear acceleration in g

$\alpha = 0.0508$

$\beta = -9.8047$

References:

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